Application of Reference Curves for Dissolved Oxygen Criteria Assessment:

Chesapeake Bay Program Office Review and Recommendations

Briefing Document for the
CBP Scientific and Technical Advisory Committee's
Peer Review Team

July 2, 2009

Background

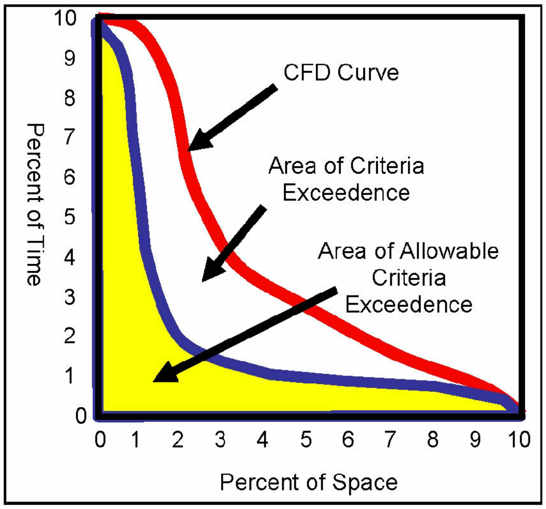
The EPA Chesapeake Bay Program Office, in close consultation with the Chesapeake Bay Program's (CBP) Water Quality Steering Committee, is closely evaluating all the data, tools, assessments and models being used within development of the Bay TMDL. EPA is seeking to ensure all the major assessment tools and models have undergone independent peer review and all issues raised have been resolved to the satisfaction of the Agency and the watershed partners.

During the CBP Scientific and Technical Advisory Committee sponsored independent peer review of the CFD procedure several years ago, reviewers raised concerns about the method for deriving the biological reference curves (Secor et al. 2006). At the time, there were not apparent solutions to resolve the concerns that were raised. However, during recent application of criteria assessment procedures to model simulated outputs, evaluation of the resultant model outputs put the spotlight back on the criteria assessment process and the underlying biological reference curve methodology.

Current Status

The current method for assessing dissolved oxygen (DO) impairments in Chesapeake Bay incorporates the use of a cumulative frequency distribution as the final step of assessment. In this step, a set of DO violation rates for a particular segment-designated use (e.g. "CB4MH Deep Water") are plotted as a cumulative frequency distribution (CFD) and compared to a "biological reference curve" comprising a cumulative frequency distribution of "acceptable violation rates" of the DO criteria. If the 2-D area under the given segment-designated use exceeds the area under the biological reference curve, then the given segment is considered "impaired" (see Figure 1).

Figure 1:



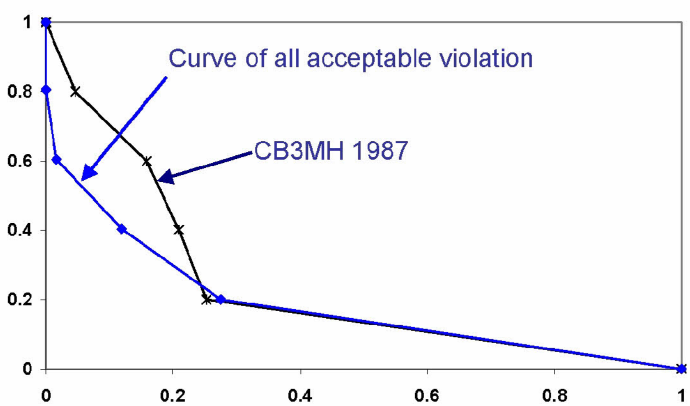
Issue

The following issue has been raised about this method for deriving biological reference curves: by combining violation rates from all healthy areas into one bioreference curve, we create a curve that theoretically represents approximately the median of all curves included. Thus, a large percentage of the presumably "acceptable" violation rate CFDs that were pooled in order to generate the bioreference curve may fail an assessment conducted against that curve.

Evaluation and Findings

A more detailed evaluation of this issue by Chesapeake Bay Program Office (CBPO) data analysts (Keisman-UMCES, Shenk-EPA) confirmed this concern. In Figure 2 below, the CFD for CB3MH Deep Water 1987, whose rates were included in the biological reference curve, fails assessment by that same biological reference curve.

Figure 2:



Further analyses revealed that the biological reference curves used for the deep water and deep channel DO criteria attainment assessment fail the majority of supposedly "healthy"

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segment-years used to construct those same curves. As a result, CBPO staff (Keisman, Shenk, Johnson-ICPRB) investigated two questions at the request of the Chesapeake Bay Program's Water Quality Steering Committee:

> **(1)** Is the Chesapeake Bay benthic index of biotic integrity (B-IBI) being applied in a manner that accurately identifies those "healthy" segments with "acceptable" DO violation rates?
>
> **(2)** Assuming reasonably accurate identification of groups of "healthy" and "degraded" benthic communities and their associated violation rates, should the methodology used to construct the biological reference curve be modified? Specifically, should the biological reference curve be constructed in a manner that distinguishes between the two datasets of "acceptable" and "unacceptable" DO violation rates with minimal error? This would be in contrast to the current published method, which simply pools all acceptable violation rates into one biological reference curve.

Analyses suggested that the currently published application of the B-IBI does not accurately distinguish between healthy and degraded communities with corresponding distinct sets of DO violations. CBPO data analysts (Keisman, Johnson) worked with Chesapeake Bay benthic experts (Llanso-Versar, Dauer-ODU) to revise the methods for identifying "healthy" and "degraded" benthic communities. Using the newly delineated "healthy" and "degraded" benthic communities, CBPO staff (Keisman) worked to produce a set of revised biological reference curves that minimize the error in distinguishing between "healthy" and "degraded" segments.

During this process, it was determined that the B-IBI provides a robust delineation of healthy and degraded benthic communities with corresponding distinct DO violation rates. However, a robust relationship was not observed between healthy and degraded benthic communities and DO violation rates in open water designated uses. Furthermore, we observed no instances of a healthy benthic community in the deep channel designated use using our revised method (described below). Thus, we are not able to identify a sufficient set of acceptable DO criteria violations sustained by deep channel benthic communities at this time.

A table identifying the currently published method, and recommended revisions to that method, is shown below:

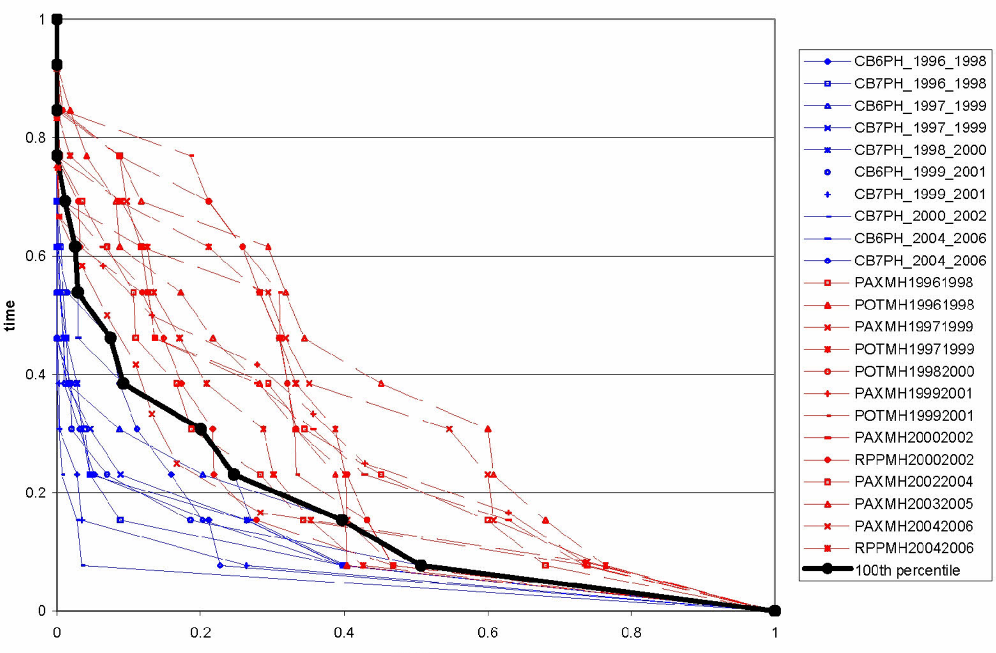
Table 1:

Current Method	**Suggested Revisions**
1. obtain dataset of all Benthic Index of Biotic Integrity (B-IBI) scores for time period 1985-200	Restrict dataset to 1996-2006 time period; for fixed station samples use "grand score" only.
2. For relevant segments (those with deep water (DW) and Deep Channel (DC) designated uses (DUs)), match benthic stations and scores in dataset with monthly open water, deep water, and deep channel designated use boundaries. Boundaries are derived using the standardized, automated method for identifying pycnocline boundaries documented in U.S. EPA's 2008 Technical Support for Criteria Assessment Addendum. Pycnocline boundaries are then interpolated using the CBP interpolator. Interpolator cells are matched with benthic station locations, and interpolated pycnocline boundaries are applied to each benthic station location.	None
3. Benthic stations (and their associated B-IBI scores) are assigned to a DU: OW, DW, or DC.	None
4. To define the biological reference community for each designated use, all segment-years for which the minimum B-IBI was ≥ 3.0 are identified	a. Use 3-year rolling time periods rather than single years. This brings the reference community ID method in better alignment with the DO criteria assessment method for which reference communities are being identified. b. Require a B-IBI score sample size >= 10. This improves the spatial representation of the B-IBI score c. "Healthy" reference communities are those with an **average** B-IBI score ≥ 3.0, standard deviation (SD) < 1.0, rather than a **minimum**. Using the **average** is consistent with methods used by benthic experts to assess benthic community impairment.

5. For the segment-years identified in step #4, the monthly (in the case of OW and DW) or instantaneous (DC) violation rates are obtained.	None
6. These violation rates (e.g. percentage of a segment-DU's volume failing the DO criteria in a given month; thus 4 measures per summer for OW and DW – June thru Sept) are used to define "acceptable" exceedances of the dissolved oxygen criteria, based on the logic that if a healthy benthic community existed in the segment-du in that summer, then the degree of DO criteria violation that occurred did not lead to an impaired benthic community.	None

Using the revised methodology, CBPO staff identified two distinct sets of "healthy" and "degraded" (average B-IBI < 3.0, SD < 1.0) benthic communities, with correspondingly distinct violation rates (Figure 3).

Figure 3: DO deep water criteria violation rates corresponding to healthy (blue) and degraded (red) benthic communities. Bioreference curve representing 100th percentile of healthy violations shown in black.



CBPO staff (Keisman) further determined that a reference curve constructed from the 100th percentile of healthy violation rates (x) for each point in time (y) accurately distinguished between healthy and degraded benthic communities with zero error in classification.

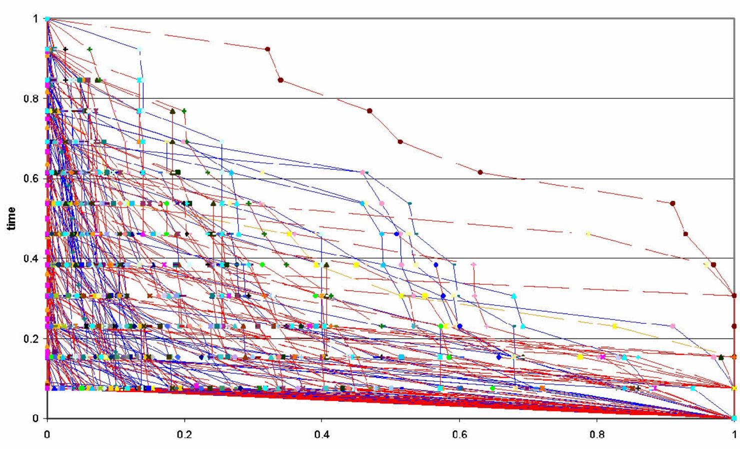
Reference Curves for Open Water and Deep Channel Designated Uses

Two additional biological reference curve-related questions were raised by the Water Quality Steering Committee and stakeholders which require input from the STAC-convened review panel:

> **(3)** Is a B-IBI based biological reference curve the most appropriate reference curve to apply in assessing attainment of the Chesapeake Bay June-September 30-day mean open-water dissolved oxygen criterion?
>
> **(4)** Is it appropriate to apply a biological reference curve in the assessing attainment of the Chesapeake Bay deep-channel instantaneous minimum dissolved oxygen criterion?

Application of a Reference Curve for the Open Water Designated Use
With regard to question **(3)** above, our analyses suggest that the B-IBI does not provide an appropriate reference community for assessment of Open Water dissolved oxygen violations. This is demonstrated by the cloudplot (see Figure 4) representing segments deemed "healthy" and "degraded" according the methodology described. Even with improvements in the methodology to distinguish between healthy and degraded benthic communities, Figure 4 illustrates that the health of the benthic community is not an appropriate indicator of open water hypoxia as defined by the open water monthly D.O. criterion.

Figure 4: Open water "healthy" and "degraded" benthic communities are not distinguished by violations of the open water D.O. criterion



In the absence of a more appropriate biological reference community for determining DO criteria violations, it may be preferable to apply the default 10% curve in assessment of DO criteria for the open water designated use. Figure 5 illustrates the 10% default curve relative to the current published open water bioreference curve. A curve representing the

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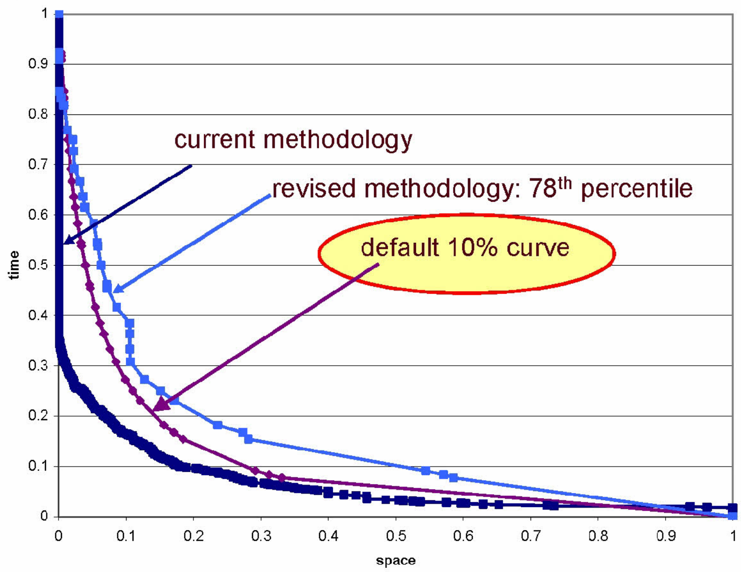
78th percentile of open water D.O. violations among healthy benthic communities is also displayed. This curve represents a best effort at "balancing the errors" of inaccurately classifying a "healthy" or "degraded" benthic community; 49 percent of healthy benthic communities fail assessment using the 78th percentile reference curve while 50% of degraded communities pass assessment using this curve.

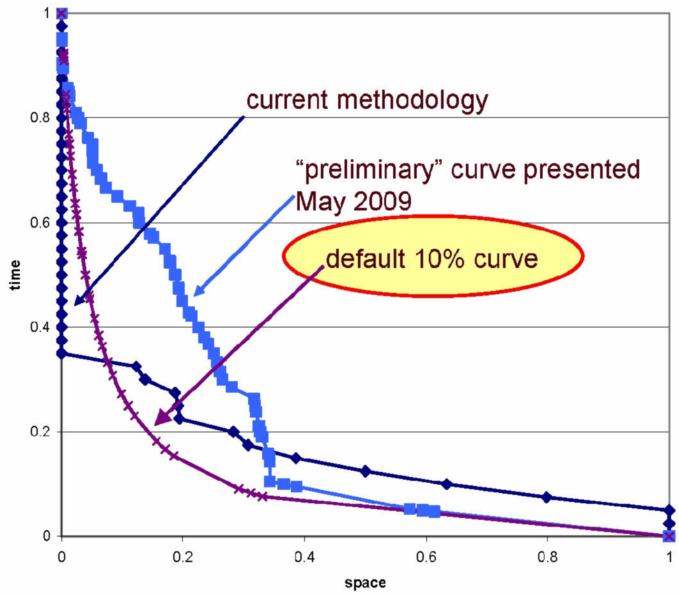
Figure 5: Comparison of open water reference curves.



Application of a Reference Curve for the Deep Channel Designated Use

With regard to question **(4)** above, our analyses suggest that the occurrence of healthy benthic communities in the deep channel designated use is currently insufficient to identify a corresponding set of "acceptable" violations of the DO criteria. Figure 6 provides a comparison of the 10% default reference curve, a deep channel reference curve generated using the currently published methodology, and the preliminary (erroneous) reference curve provided to the Water Quality Steering Committee in May 2009.

Figure 6: Comparison of deep channel reference curves



The question of whether to apply the 10% default reference curve to DO violations of the deep channel instantaneous minimum criterion remains. In the original Chesapeake Bay water quality criteria document (U.S. EPA 2003), EPA recommended the application of a biological reference curve for assessment of the deep-channel dissolved oxygen criterion. A specific bioreference curve was not published at that time, therefore, the default reference curve was recommended for application.

The following text was extracted from the 2003 Chesapeake Bay criteria document, page 173:

> The deep-channel seasonal refuge designated use contains dissolved oxygen concentrations that are inadequate to support most Chesapeake Bay species, and the criterion is set to protect the survival of benthic organisms. Unfortunately, a biologically-based reference curve could not be developed for the deep-channel use at this time. This area is assumed to be severely degraded and is not now sampled as part of the Chesapeake Bay Program long-term benthic monitoring program. No other appropriate biological data were available with which to identify reference sites.
>
> While a biologically-based reference curve is recommended for the future, a default reference curve such as the normal distribution curve representing approximately 10 percent exceedance is appropriate in this case to account for anticipated natural criteria exceedances (Figure VI-18). States and other users must recognize that the deep-channel dissolved oxygen criterion is stated as an instantaneous minimum, thus any exceedance is assumed to have direct consequences to the survival of the bottom-dwelling community.

Based on further work on the bioreference curves during the 2005-2006 timeframe, a bioreference curve was derived based on benthic index of biotic integrity (B-IBI) data from stations determined to sample deep-channel designated use habitats during the summer months. The bioreference curve was derived based on data from stations which did not attain the instantaneous minimum deep-channel dissolved oxygen criterion yet supported a healthy benthic infaunal community (represented by a minimum B-IBI score of 3 or greater).

The following text was extracted from the 2007 Bay criteria addendum document (U.S. EPA 2007), pages 42-43:

> The April 2003 Chesapeake Bay water quality criteria document provides conflicting guidance in the use of reference curves for assessing attainment of the four instantaneous minimum dissolved oxygen criteria. Pages 170 to 173 in U.S. EPA 2003a display and discuss reference curves for migratory spawning and nursery, open-water, deep-water, and deep-channel criteria attainment assessment. All four sets of designated-use specific criteria include a use-specific instantaneous minimum criterion. With the exception of the deep-channel criteria (page 173 in U.S. EPA 2003a), none of these sections specifically describe whether a reference curve should be applied in assessing attainment of the respective instantaneous minimum criteria. The reader is left with the sense that the published reference curves should be applied to all the dissolved oxygen criteria, regardless of the stated duration.
>
> All four instantaneous minimum criteria for protection of the four designated uses—migratory spawning and nursery, open-water, deep-water, and deep-channel—protect against mortality from very short-term exposure to low dissolved oxygen concentrations (U.S. EPA 2003a). The other dissolved oxygen criteria with specific averaging periods (30-day, 7-day, and 1-day means) protect against impairments—including growth, respiration, and behavioral/avoidance—for which the impairments will not impact the designated use. The 2003 EPA criteria guidance stated that there were no "biologically acceptable exceedances of the applicable criteria" for the instantaneous minimum criteria, given that the impairment is death (page 151 in U.S. EPA 2003a).[1]
>
> While updating the methodology for deriving the open-water and deep-water designated-use dissolved oxygen criteria reference curves for the 30-day mean criteria (described above), there were times and locations in the Chesapeake Bay for which healthy benthic infaunal communities still existed despite exceedance of the 1 $mg \cdot liter^{-1}$ instantaneous minimum

[1] Please note that an electronic text search of the 2003 EPA Bay criteria document did not yield the location of the statement 'there were no "biologically acceptable exceedances of the applicable criteria" for the instantaneous minimum criteria, given that the impairment is death' anywhere within the subject document.

criterion. The EPA recommends, therefore, that attainment assessment of the instantaneous minimum deep-channel dissolved oxygen criteria be conducted with the CFD methodology using the deep-channel biological reference curve (Figure IV-4; Appendices F and G).

Given the previously described concerns about the present methodology for deriving the biological reference curves, the proposed revised methodology was applied to derive a revised deep-channel bioreference curve. The revised method yielded no segments meeting the revised criteria outlined in Table 1 above. Furthermore, areas greater than 12 meters deep (the "deep trough") are excluded from the benthic sampling program "because these areas are subjected to summer anoxia and have consistently been found to be azoic" (http://www.esm.versar.com/Vcb/Benthos/history.htm). To truly represent the condition of deep channel benthic communities in segments containing both a deep channel designated use and depths deeper than 12 meters (CB4MH, CB5MH), a post-hoc analysis incorporating the excluded area would need to be performed.

Evaluation of 1950s dissolved oxygen data from Chesapeake Bay and its tidal tributaries yields periodic values below 1 mg liter^{-1} even in the absence of the persistent anoxic conditions characteristic of past several decades. Model simulation of an all-forested, pristine watershed yields occasional dissolved oxygen concentrations below 1 mg liter^{-1}. Given these findings, EPA has continued to recommend assessment of the deep-channel dissolved oxygen using the appropriate reference curve.

References:

Secor, D., M. Christman, F. Curriero, D. Jasinski, E. Perry, S. Preston, K. Reckhow and M. Trice. 2006. The Cumulative Frequency Diagram Method for Determining Water Quality Attainment-Report of the Chesapeake Bay Program STAC Panel to Review of Chesapeake Bay Program Analytical Tools STAC Publication 06-9 October 2006. Chesapeake Research Consortium, Edgewater, MD

U.S. Environmental Protection Agency. 2003. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries.* EPA 903-R-03-002. Region III Chesapeake Bay Program Office, Annapolis, Maryland.

U.S. Environmental Protection Agency. 2007. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries–2007 Addendum.* EPA 903-R-07-003. CBP/TRS 285-07. Region III Chesapeake Bay Program Office, Annapolis, Maryland.